Beidou QZSS L1C MSAS 0d-mode GHz
COMPASS Galileo L5 DGPS GPSDO
EGNOS SA saw tooth
GLONASS L2C WAGE speed of light
GNSS GPS L1 WAAS SBAS nanosecond

Time transfer systems:
Setting your clock by GPS

"the times they are a changing"

RS-232 LinuxPPS ACTS CDMA Securties SOX
PPS USB NTP gpsd WWV Trading Femto GLBA
PTP Cell T1.101
EXTINT IEEE1588 LORAN GSM GR-1244 HIPAA
NMEA IRIG DCF77 NITZ ETSI IEC-61850

Author: Mark Willis 2012.

Presented at: Sydney Linux Users Group (SLUG) Nov. 2011.

Filename: SLUG_2011Nov_GPS_timesync_slides.pdf

See also: SLUG_2011Nov_GPS_timesync_notes.txt

Timing Talks: Series Aims.

- To provide a quick **background** on precision **time synchronisation**.

  To allow people to choose a level of time synchronisation they require.
- From simply setting the time periodically to high precision timing.

⇨These talks are NOT intended to be a how-to, these are available online.

Disclaimer: First I should say that GPS and radio frequency engineering, along with time synchronisation and are highly technical and specialised fields.

My interest is in precision time synchronisation with a high degree of assurance. Currently GPS is the best method to achieve this goal.

What this talk will NOT cover.

- Navigational GPS use is NOT the focus of this talk.
- However much of the information that I will cover about **future of GPS** and **systematic limits**, is applicable.
- In particular **precision navigation** & reception in **challenging situations**.
- In fact I have little knowledge about mapping and user interfaces.

The aim of today's talk.

This talk is intended as an introduction to NTP and GPS time transfer:

- To examine why you might need precision **time synchronisation**.
- How in Australia, **GPS** is the **only** real **option** for precision time transfer.
- Then to look at the current state and the **future** of the **GPS** system.

Contents of today's talk:

1. • Reasons for precision timing.
   • NTP & synchronisation systems.
2. The future of GPS/GNSS.
3. Choosing a receiver & PPS output.
4. Additional hardware & antennas.
5. Connecting hardware together & reception problems.
6. Chasing the nanoseconds.

Part 1: Introduction to timekeeping.

1.1 Reasons for precision timing.

1.2 NTP “the default choice”.

1.3 Reference Clocks and NTP.

1.4 Choice of time synchronisation systems (GPS, Radio Clock).

1.5 Indirect time sources (CDMA, NITZ, SONET/SDH, RDS etc.)

Why should I care?

“**Accurate to nearest minute is good enough for anybody.**”

```
Starting MS-DOS...
Current date is Thu 01-03-1980
Enter new date (mm-dd-yy):
Enter new time:
```

[TRANSCRIPT] **Why should I care?**

- Time on **Apple** phones and mobile devices is only guaranteed to be accurate to the **nearest minute**.
- Due to the vagaries of **leap seconds**, on **Microsoft** platforms time is only guaranteed to within a few seconds.
- Some **Android** devices do not apply **leap second** offsets correctly.

Reasons for Accurate and Precise time synchronisation:

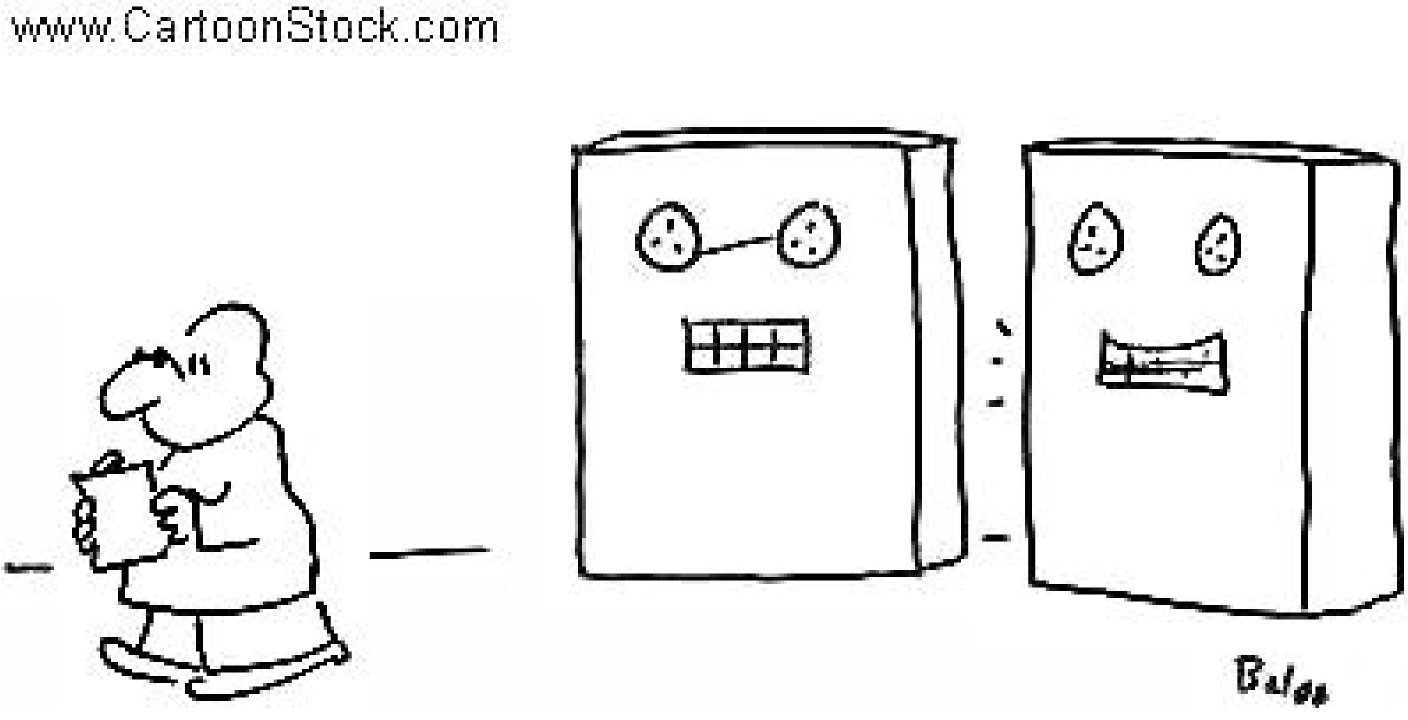
- Legal/Regulatory compliance – SOX, PCI-DSS, System log files.
- Transaction time stamping.
- Network performance monitoring.@
- pool.ntp.org is a public service.
- eBay auctions ;-)
- Because you can...

@ SEE: http://bufferbloat.net/

What level of Precision?

- With increasing work volumes – each **transaction(s) occupies less time**, therefore higher precision is needed.
- Network performance: high speed & **multiple locations** are commonplace.
- Computers are replacing specialised electronics in **time critical systems**.
- Public expectations have increased.

What level of Precision?



"He won't be back for a few nanoseconds — care for a game of chess?"

Regulatory compliance. (IANAL)

- If it's the law: **comply or don't exist.**
- International regulation: achieve the highest common denominator.

  SOX, HIPAA, PCI-DSS, ETSI etc.
- To avoid negligence claims, you need to demonstrate accepted practice.
- Proving time is expensive/impossible to do after an event.

Industry	Timing	Frequency
Financial Markets	3 sec(US OATS) 1 sec(PCI-DSS)	-
Telco. Legal	200 ms	-
Telco. Mobile	10 µs	5×10^{-8}
Telco. T1.101	0.864 µs	10^{-11}
Electricity Grid	1 µs	10^{-7}
TV(digital)	5 µs	1.5×10^{-9}

RECAP: Part 1: General timing topics

1.1 Reasons for precision timing.

1.2 NTP the default choice.

1.3 Reference Clocks and NTP.

1.4 Choice of time synchronisation system (GPS, Radio Clock).

1.5 Other indirect sources (CDMA, NITZ, SONET/SDH RDS etc.).

<u>NTP the "Hoover" of time sync.</u>

- NTP is the default method of time distribution over the Internet.
- Everything from national timing labs to DSL routers use NTP.
- If all you want is accuracy/precision of **1-100 milliseconds**, NTP over the **Internet** will do.

NTP: Time Sync Choices.

1. Workstations: **periodic SNTP** (ntpdate) queries (cron/if-up).
2. Servers: **run ntpd**: “more important” and run 24/7 (ntpd can take up to a couple of hours to settle down)

2b. Servers: run ntpd with an **external Reference Clock(PPS)** - additional hardware and time to settle down.

Why an external Reference Clock?

- **Higher precision**/accuracy.
  - Compensating asymmetric delays.
  - High jitter Internet connections (3G).
- **Higher assurance**.
  - Diversity/direct access.
  - Potential NTP security problems.
  - No Internet connection.
- Need precision frequency(GPSDO).
- The mountain is there to climb ;-)

Alternatives to time over the Internet.

	Assurance	Precision
Internet NTP Query	🕒🕒🕒½	1-100ms
Dial-Up Modem (ACTS)	🕒🕒🕒🕒	10 ms
HF Radio (WWVH Hawaii)	🕒🕒🕒	1 ms
Longwave Radio (WWVB, DCF77, JJY, LORAN)	🕒🕒🕒¾	10 µS
GPS/GNSS (GLONASS, Galileo, COMPASS, SBAS)	🕒🕒🕒🕒½	< 10 ns

Australia: Options for time transfer.

	Assurance	Precision
Internet NTP Query	🕘🕘🕘½	1-100ms
Dial-Up Modem (ACTS)	PHONE CALL PER SYNC	
HF Radio (WWVH Hawaii)	UNRELIABLE (in Australia)	
Longwave Radio (WWVB, DCF77, JJY, LORAN)	NOT AVAILABLE (in Australia)	
GPS/GNSS (GLONASS, Galileo, COMPASS, SBAS)	🕘🕘🕘🕘½	< 10 ns

[skip] **Indirect Synchronisation.**

Another option is to use an indirect method – usually to a GPS receiver.

- CDMA(10μs), GSM NITZ(whole seconds), ISDN, E1/T1, SONET/SDH, TV signals, FM RDS(100ms) (phone AGPS uses other methods)
- Before the “Internet everywhere” and GPS, these were a good **solution to** the **blinking 12:00** problem.

[SKIP]

The biggest problem you are relying on organisations (such a TV stations) for which **time synchronisation is NOT a core a function.**

(Also many of these schemes have a lower precision than Internet NTP)

Part 2: The Future of GPS/GNSS.

2.1 GPS time too good to be true.

2.2 GPS and the military.

2.3 Why should I trust GPS?

2.4 GPS constellation status.

2.5 Modernised GPS (L2C, L5, L1C).

2.6 Other constellations (GLONASS, Galileo, et al.)

<u>GPS/GNSS is The Best Option</u>.

(even if there was a choice).

- **GPS** is the international **de facto standard** for precision time transfer.
- GPS is no longer primarily a US military system – GPS/GNSS is an international **critical civilian service**.
- GPS synchronisation is now **cheap!** ($10-35 for a suitable GPS receiver)

[skip] **Why should I trust GPS?**

- GPS is operated by the US military & **relies** very **accurate time** signals.
- Differences between GPS and **UTC(USNO)** are published.
- Precise time synchronisation has been important to the navy after Harrison's Marine Chronometer solved the Longitude Problem.

The military gets the “cool” stuff?

- People can confuse errors from SA with dual frequency improvements.
- **L2** has 65% **more ionic dispersion**.
- L2 can be broken into with L1 info.
- RTK/**Carrier phase** (L1, codeless L2) give the **highest resolution** (sub cm).
- Multi constellation beats dual frequency, (n.b. **urban canyons**).

Stuff that ONLY the military gets.

Important differences between the civilian and military GPS signals:

- Anti Spoofing: Out of band key transfers needed/SAASM. (However a GPS simulators cost >$10k) *note
- Anti Jamming: But due to the weak GPS signal, a **cheap** wide band **jammer** will obliterate **both signals**.

GPS Modernisation

(civilian users are now important)

- No Selective Availability(SA).
- **SBAS**(WAAS, EGNOS, MSAS).
- 24+3 configuration (currently **32 satellites** – original design: 24).
- L2C (1.2 GHz) **civilian L2** signal.
- **L5** (1.1 GHz) Safety Of Life signal.
- L1C (1.5 GHz) signal improvements.

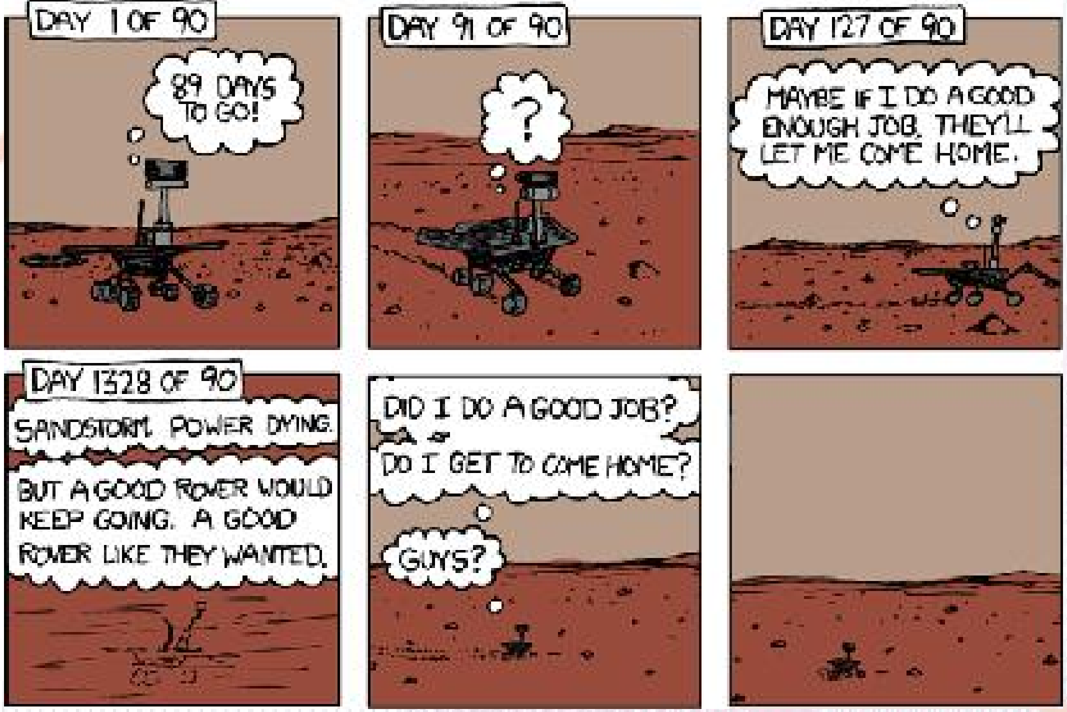
GPS Satellite History (Nov 2011).

Projected satellite lifetime:	7 ½ years
Oldest(still in use):	21 years
Average Age:	11 years
Cost per sat. inc. launch:	~$125 million
Current Constellation size:	32 (designed 24)
First Launch:	1978 (33 years ago)
Declared operational:	1993 (15 years ago)
Satellite capabilities (civilian):	[no. of sats]
Block IIA (L1 1.5GHz)	11
Block IIR (L1 1.5GHz)	12
Block IIR-M (L1, L2C 1.2GHz)	7
Block IIF (L1, L2C & L5 1.1GHz)	1 (+1 in testing)
Block III (L1, L2C, L5, L1C 1.5GHz)	under construction

Next IIF launch scheduled for Sep. 2012

[skip] **GPS Satellite Retirement:**

"There's a chance the sat. will come back, It did go active years ago... maybe they just want cut the springs, bolt a wing on the back and add some racing stripes!"



FROM: http://xkcd.com/695/
(CC BY-NC)

GPS is not the only show in town.

Other satellite navigation systems:

- GLONASS (**.RU**)(operational)
- Galileo(**.EU**)(planned)
- COMPASS/Beidou(**.CN**)(planned)
- QZSS(**.JP**)(1/3 satellites launched)
- SBAS (WAAS, EGNOS, MSAS) used directly rather just than for DGPS.

[skip] <u>**GLONASS**(.RU) **as Plan B.**</u>

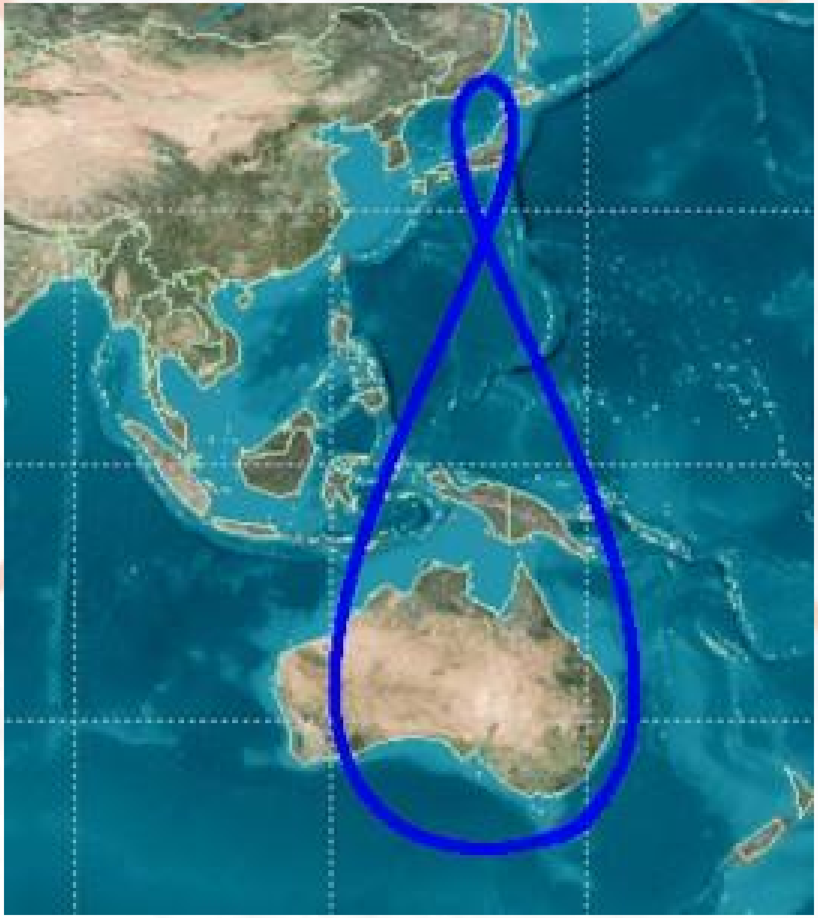
- After cold war, fell into disrepair.
- Uses old style FDMA (1 CDMA sat.)
- Above L1 GPS antennas bandwidth.
- Has **rubber leap seconds** problem.
- Few/poorly documented receivers.
- Timing receivers not yet available.
- **Mainly useful for urban canyons.**
- Still susceptible to GPS jamming.

[skip] **<u>Galileo and COMPASS.</u>**

- <u>Galileo</u> in development >15 years. (before Selective Availability ended)
  - In Orbit Validation sats launched.
- <u>COMPASS</u> (.CN) is a newer project.
  - First sats are in geosync. orbits. (some coverage of Australia)
- **Both** will transmit on **L1C & L5**
- First receivers appearing.

[skip] **Japanese QZSS** (& Australia).

Transmits on GPS **L1, L1C, L2C, L5**.
3 Satellites - **Tundra** orbits (1 launched)



(CC)

[skip] **Japanese MSAS SBAS.**

- Australia: **only visible DGPS sats**
- 2 Sats in geostat. orbit over PNG.
- PRN129 & PRN134
- Transmits on L1, L5.
- Australian Gov. did not participate so **ionosphere corrections are not valid**. (even though there is a Japanese MSAS monitoring site in Australia!)

The problem with both multi-frequency GPS (L2C, L5, L1C) and alternative constellations (GLONASS, Galileo, COMPASS) – there are no affordable timing receivers that implement these features:

… Yet.

<u>Currently GPS L1 is the only choice.</u>

(U-Blox – have promised Galileo firmware upgrade)

(Galileo/COMPASS sats are yet to be launched)

Part 3: Choice of GPS receiver

Holden vs Ford.

3.1 How many sats/channels?

3.2 Consumer receivers don't really care about time.

3.3 You need a PPS.

3.4 Timing receivers are nice.

3.5 GPSDOs are better.

How many sats/channels to I need?

By recording the time of arrival from **4 satellites** it is possible to solve for 4 unknowns – **3 dimensions** of space and **1 for timing** error.

- Additional satellites increase accuracy, configuration matters.
- 24 sats design (12 visible).
- 99 Channel receivers available.

Non-military GPS Users.

1. Consumer Navigation – a **nice interface** is most important.
2. Professional Navigation – **high assurance** systems are essential.
3. Land Survey – **high precision** with capital costs and post processing.
4. Timing Receivers – real time, used in **critical infrastructure**.

<u>All animals are not created equal.</u>

- Even though the GPS navigation depends on high precision timing, you **need** a receiver that allows you **to access this precision**.
- The clock display on most “navigation receivers” is secondary feature, so manufacturers take little care beyond avoiding gross errors.

You NEED a PPS signal.

- The most common method GPS receivers use to convey precise time is a Pulse Per Second(PPS) signal over a RS-232 serial line.
- Most **consumer** GPS receivers **don't export** the **PPS** line and/or use USB. (NMEA and USB messages have a high jitter)

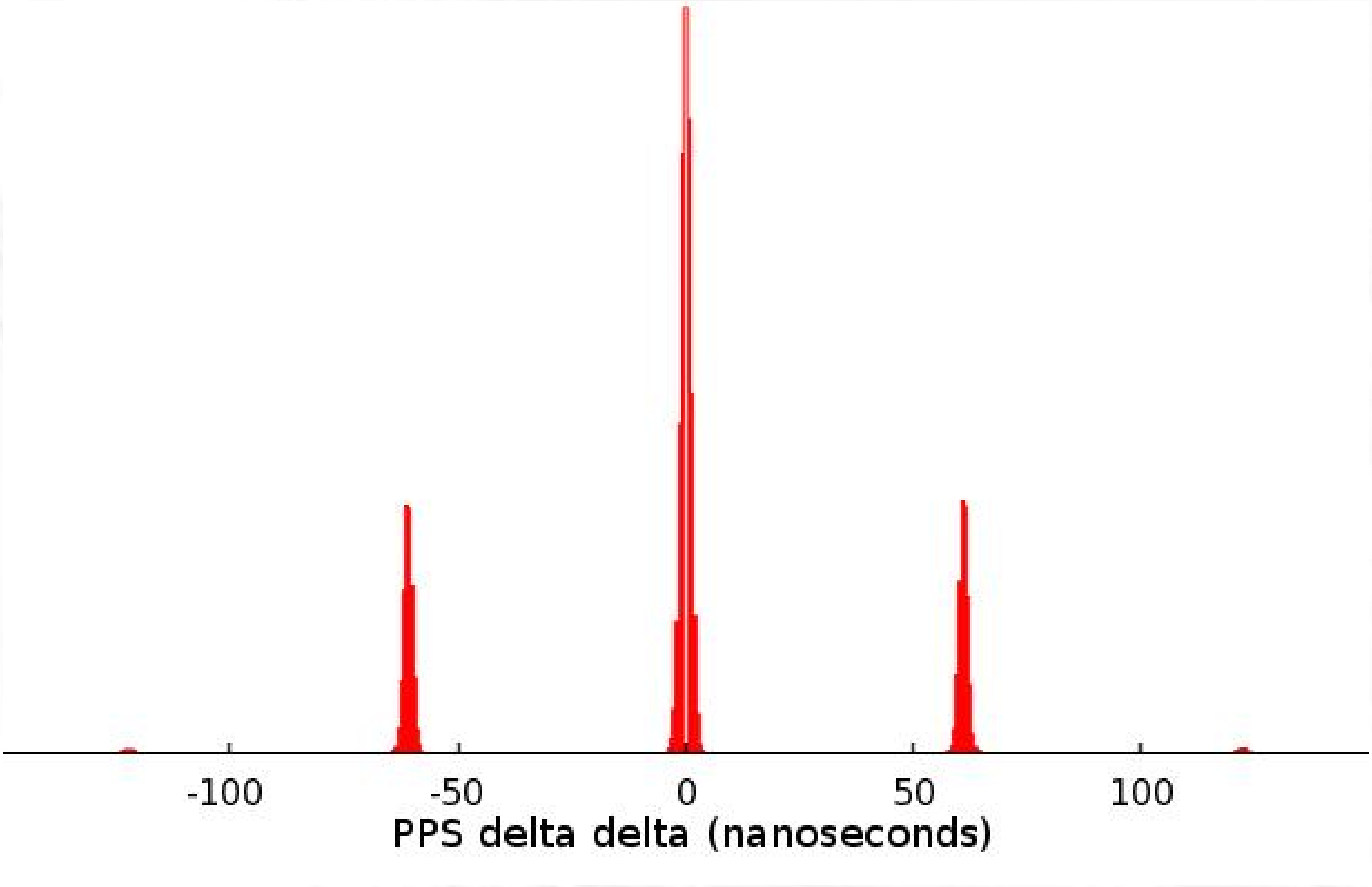
A few consumer receivers:

a. Garmin(integrated antenna) **18LVC, 18LVCX, 16LVC, 16HVS/17HVS**.

b. **Sure Electronics** GPS-10 (US$34)

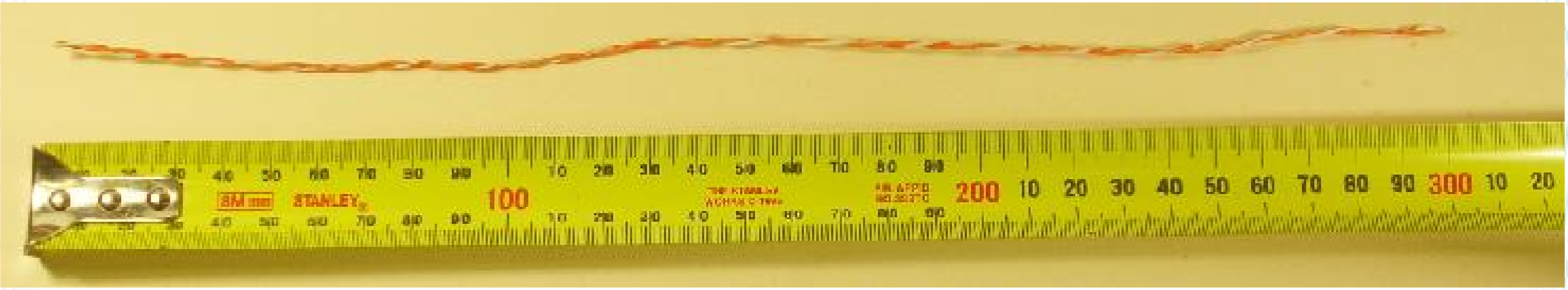
- Accuracy of 1 µs is often quoted: an old and very conservative spec. more pessimistic than errors caused by SA (1µs = 300m accuracy).
- 18LVC has a 130 nS sawtooth.

Garmin 18LVC PPS ΔΔHistogram



FROM: http://n1.taur.dk/permanent/hist3.png (with permission)

Can someone tell me what this is?



(CC BY-SA) by author

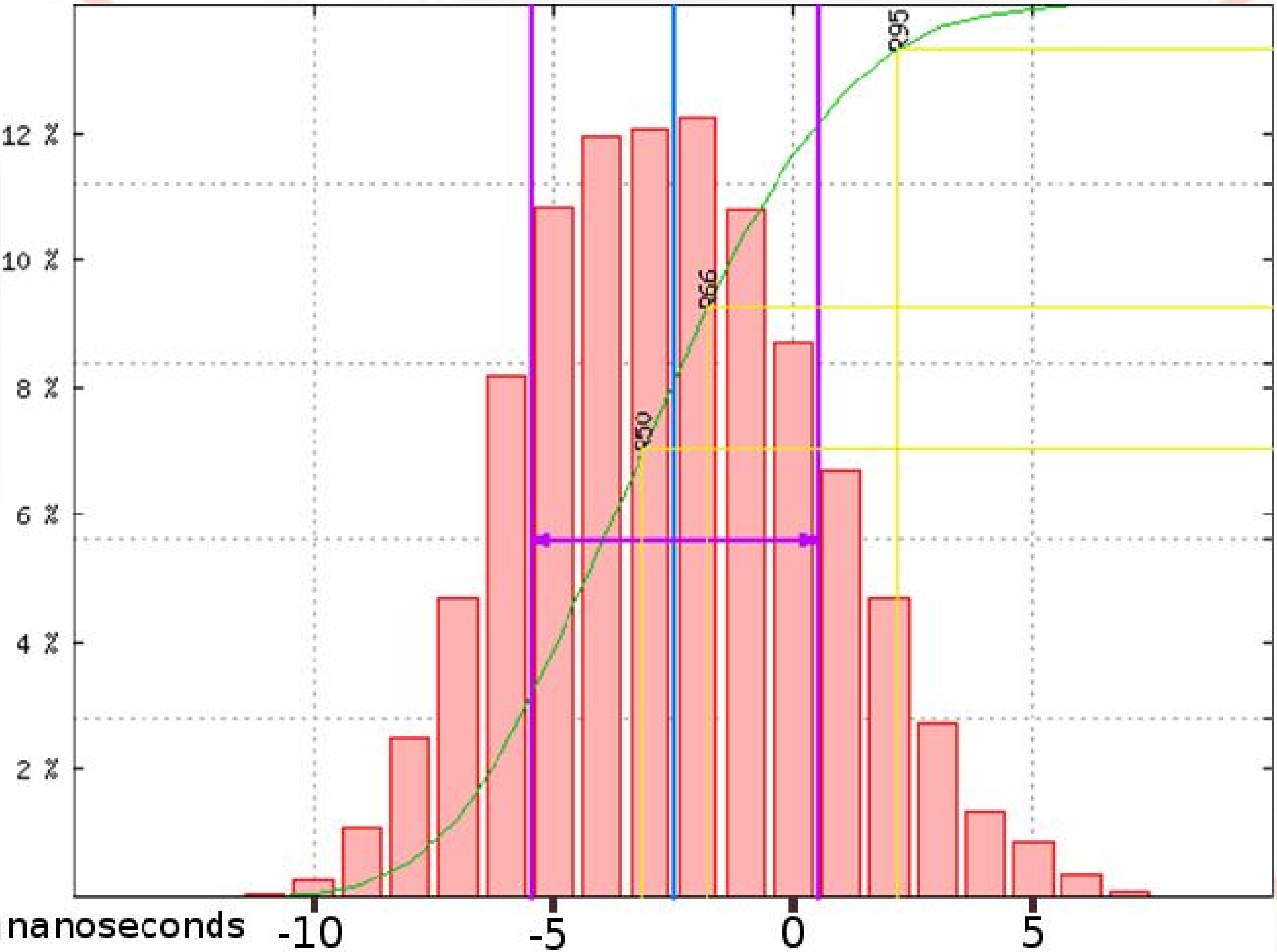
Answer: 1 nanosecond

Timing receivers advantages:

"a better class of receiver"

- Time generation is a core function.
- **Position hold** (zero-D) mode, 1 satellite required rather than 4.
- **Sawtooth** correction.
- Higher precision outputs. (<10 ns)
- Resistance to interference (cell. base stations have lots of RFI).

[skip] **Histogram U-Blox LEA-6T**



FROM: http://www.u-blox.com/

Timing receiver disadvantages:

- Higher **cost** (new-old stock $15-50)
- May need to purchase an antenna.
- Often don't get firmware updates. (Get it right first time – outages cost)
- Usually **TTL serial** – need to use a MAX232 level convert circuit. (~$4)

Timing Receiver Choices

Limited number of brands/models:

- Motorola: **m12**-t, m12+-t, m12m-t (now iLotus & Symmetricom)
- Rockwell-Collins: **JupiterT** (now Conexant → SiRF → Navman)
- Trimble (receivers and **GPSDO**s)
- U-Blox: LEA-4**T**, LEA-5**T**, LEA-6**T**

GPSDOs do it better.

- GPS signals have short term **noise** & medium term wander (diurnal).
  - Short term noise can be **averaged** out by an ovenised oscillator (**OCXO**) after the GPS receiver. Know as a GPS Disciplined Oscillator(GPSDO).
  - SBAS corrections may help with diurnal and solar wander.

Size/Price/Quality differences.

"A tale of two Oscillators"

GPSDOs without GPS!

- GPSDOs allow the PPS to continue if/when **GPS** is **interrupted**.
- Without GPS, an OCXO will slowly wander, but information gathered with GPS allows better hold over.
- OCXO may **run** for up to **a day** before it is **detectable** by NTP.

[skip] **Discipline your self?**

- GPSDOs contains **three** main **parts**
  1. **GPS** receiver.
  2. **OCXO** (crystal oscillator)
  3. **Controller** to **glue** these two together (disciplining circuit).
- First two are readily available, the disciplining circuit can be a home brew PIC or AVR microprocessor.

GPSDOs: The China effect.

- The major use for GPSDOs are mobile phone base stations(E911).
- Decommissioned base stations are sent to **China** as scrap.
- Tested Trimble **Thunderbolt**s kits are now available for **US$200**.

Summary: GPSDO Advantages

- **Lower noise** & better **hold over**.
- GPSDOs are a **frequency source** – replace motherboard oscillators, and supply other timing gear.
- GPSDOs can be turnkey solutions, fewer interface needs – no MAX232 and power supply.

Summary: GPSDO Disadvantages

- More **expensive**: ~10x the cost.
- 10MHz output needs be converted to be useful e.g. 14.318 MHz.
- Thunderbolts need a **pulse stretcher** for PC use. (TAPR FatPPS US$60)
- In the end NTP/GPS will always win over OCXO wander. (NTP is a cheap low resolution GPSDO**)

“If you are not accurate to the nearest nano/micro second, you are not really trying!” :-)

Part 4: More Hardware !!!

4.1 One receiver is a single point of failure (firmware bugs !#$!%).

4.2 Receivers are cheap, just throw hardware at it (electronic failure).

4.3 Good antennas & positions.

4.4 Multiple antennas.

4.5 Splitters GPS and PPS.

4.6 GPS outages (solar, jamming)

Embedded software Sox.

"Untested code is broken code."

There might be updates but this like "polishing poop".
(SEE: Garmin 18x updates)

Please excuse the language on this slide.

Black Box GPS

- GPS receivers are like mobile phones, even if the interface is Linux based, the interesting stuff is done is **closed source firmware**.
- In designing a GPS receiver, **assumptions** need to be made.
- We can only **guess** at firmware **quality**.

*“A person with one clock,
knows the time precisely.*

*A person with two clocks,
is never sure what the time is!”*

- One GPS receiver is a Single Point Of Failure (SPOF).
- With two receivers you can only ever have a disagreement.

Have a back up plan or three!

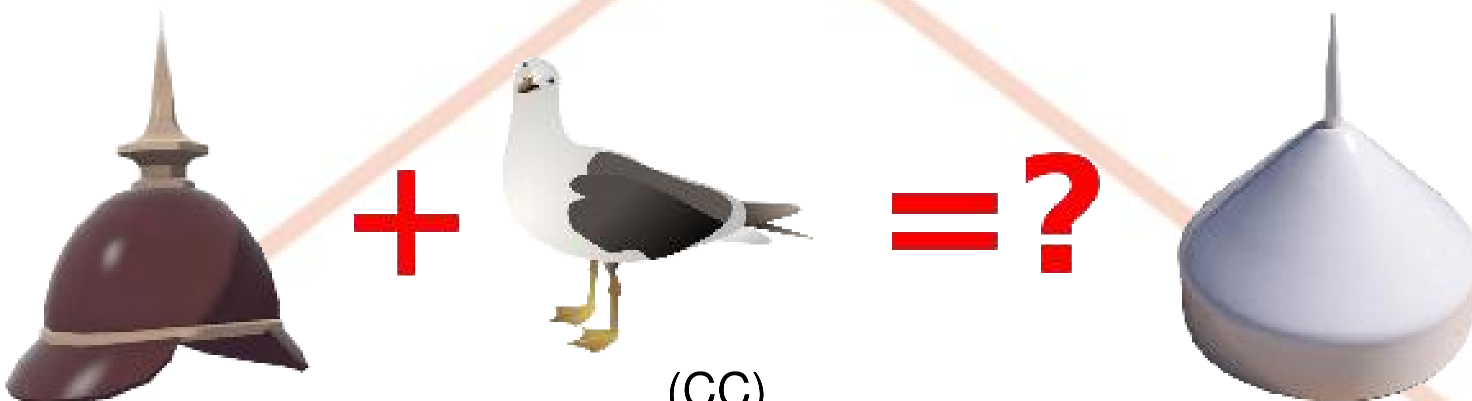
- NTP can find “**false tickers**”, so “just throw (GPS) hardware at it”.
- The magic numbers are **1,3/4,5,7**...
- All we need are the majority of the receivers to be correct.
- Use a **diversity of manufactures**.
- A usable PPS may continue even when the serial string is incorrect.

[skip] **Which Antenna?**

- With a separate antenna the sensitive receiver is inside out of the **weather**.
- Timing grade antennas have good **RFI** filtering / narrow bandwidth.
- **VIC-100** is a good choice (new-old stock sells for US$40) (L1 C/A only)
- Use 75Ω sat. TV RG-6, even though you should use 50Ω cable.

[skip] **GPS Radomes:**

“The peak is to not a lighting rod, it's to stop avian carriers from dropping their packets”

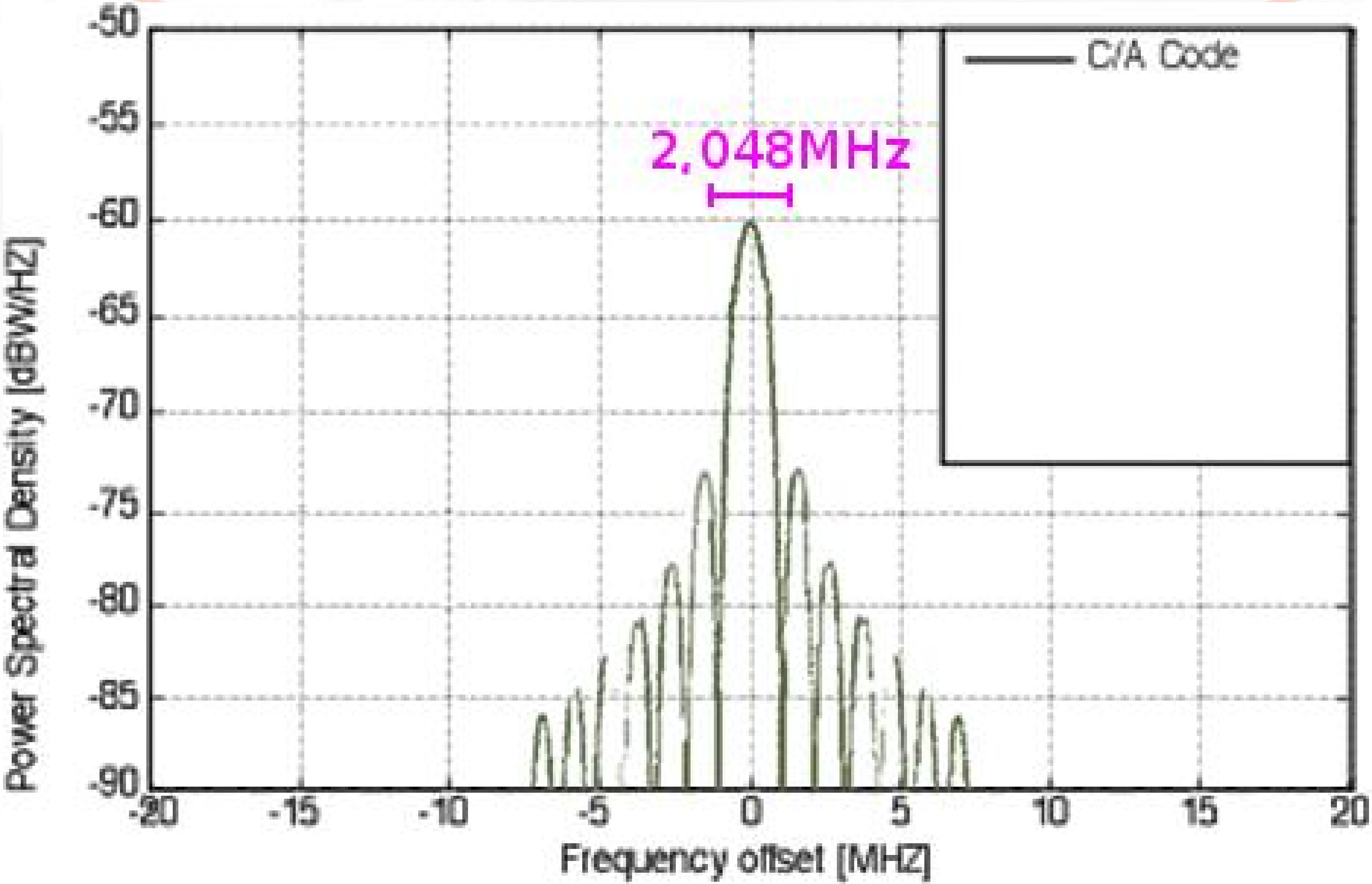


(CC)

[skip]**Future Proofing Your Antenna.**

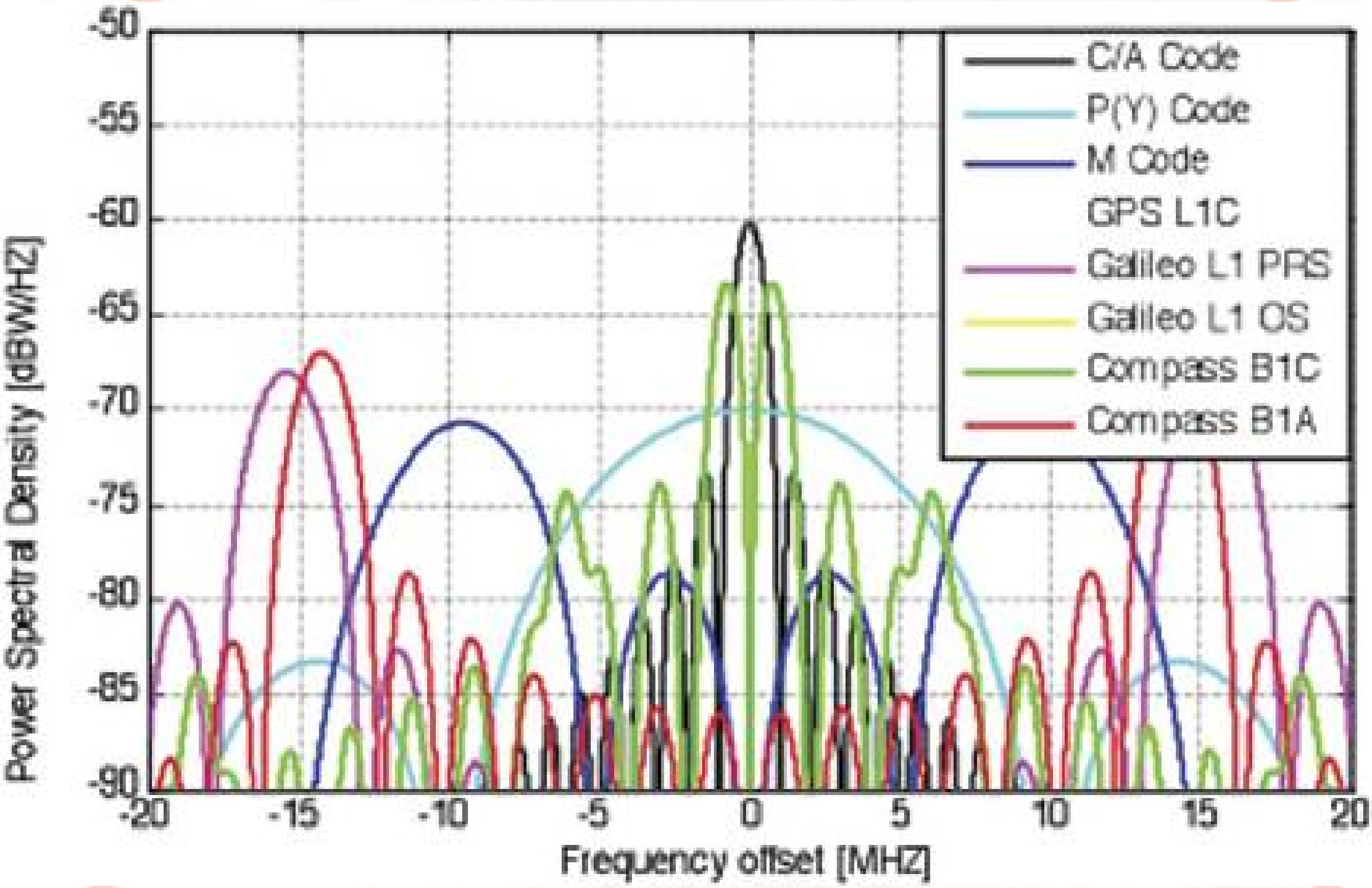
- GPS L1, **L2** and **L5** are different frequencies, so require multiple antennas or a **different design**.
- Galileo & COMPASS L1(& L5) **straddle GPS** so existing antennas may work.
- GLONASS L1 is just **above** the **bandwidth** of most **GPS** antennas.
- SBAS(DGPS) is on GPS L1.

[skip] **First we had L1 C/A**



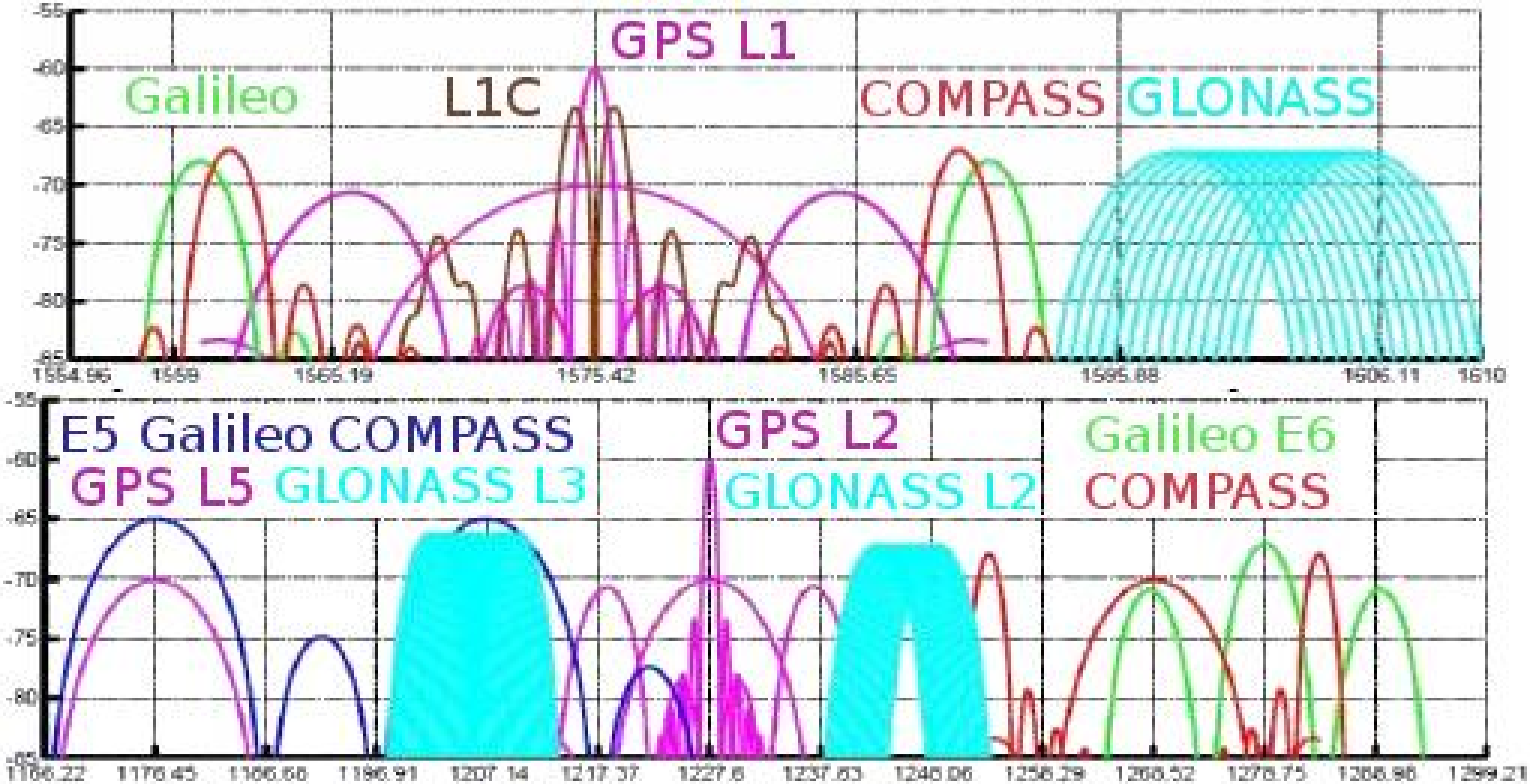
FROM: http://gpsworld.com/ [edited]

[skip] **Now L1 is busy neighbourhood.**



FROM: http://gpsworld.com/

[skip] **It's not just L1 any more.**



FROM: http://fastraxgps.com/ [edited]

GPS signals require line of sight

- For portable applications signal outages are normally not a problem.

⇨ When the vehicle/person moves the interference may go away.

- **Static locations** may need height to see over trees and **local obstacles**.
- In Australia **northern sky** visibility (towards equator) is more important.

[skip] **GPS works in buildings!**

- Modern GPS receivers are very sensitive – often work indoors.
- Depends on your roofing material.
- Usually track fewer satellites.
- May need the almanac via AGPS.
- **North facing windows** may provide reasonable reception (in Australia).
- Lightning protection ;-)

[skip] **Multiple GPS Antennas.**

- GPS **signals** are weak and amplifier leakage may **interfere** with other antennas and receivers.
- Best practice is for antennas 10m apart (inverse square law applies).
- Multiple antennas give **diversity** from **lightning strikes**, but keep receivers electrically isolated.

[skip] <u>**Multiple receivers, One antenna.**</u>

- Receivers with external antennas can use a antenna splitter.
- <u>Passive</u> satellite TV splitters will do: divides the signal strength, receivers **may interfere** with each other.
- <u>Active</u> (amplified) splitters tend to be single frequency(L1 only), but often have strong **filtering** and isolation.

[skip] **Multiple receivers, One antenna.**

GPS signal outages.

- **GPS** is now so important it has now become **single point of failure**.
- GPS outages have brought down mobile phone & telco. networks.
- Causes:
  - Geopolitical GPS Jamming
  - Solar weather(“sun spots”)

Part 5: Connecting your GPS

5.1 Level Converters

5.2 Power supply

5.3 Electronics requirements.

5.4 RF connectors.

5.5 Garmin Interface Connections.

5.6 Sure Electronics GPS.

5.7 PPS and Frequency Distribution.

Receiver Interface Electronics

- Do NOT connect TTL to RS-232.
- A TTL PPS may need a **level shifter**, but most computers are OK.
- **Power supply**: often steal power from the host computer (USB/12V).
- 3 volt boards may need a 5 volt supply for the antenna.
- Antenna/RF/Interface connectors.

[skip] **Garmin Interface 18LVC/16HVS**

- Available for < $100.
- MediaTek based chipset.
- **Combined antenna** and receiver.
- **Serial/PPS output** - no “GHz coax”
- Need to attach serial D-9 plug
- 18LVC can be powered from USB.
- 18LVCX upgrade to latest firmware.

[skip] <u>**Sure Electronics GPS kit.**</u>

- New on the market.
- SkyLab chipset (**MediaTek** based).
- Soldering of questionable quality.
- US$34 approx delivered.
- Uses USB for power.
- A small modification to get PPS.
- **Serial**, **USB** & **Bluetooth** interfaces.
- Includes a separate antenna.

PPS Distribution Amplifiers.

- Allows one GPS to be used by multiple computers/instruments.
- **Alternative to NTP** everywhere.
  - Get serial data via network.
  - Combined/Separate Serial MUX.
- Two way splitting may work with simple electrical T junction.

Part 6: Chasing the nanoseconds

how far can and should you go?

6.1 Computers fumble nanoseconds.

6.2 Sawtooth errors.

6.3 Diurnal variations.

6.4 UTC traceability.

[END OF PRESENTATION]

6.5 !#@$ leap seconds.

Precision Achievable by GPS.

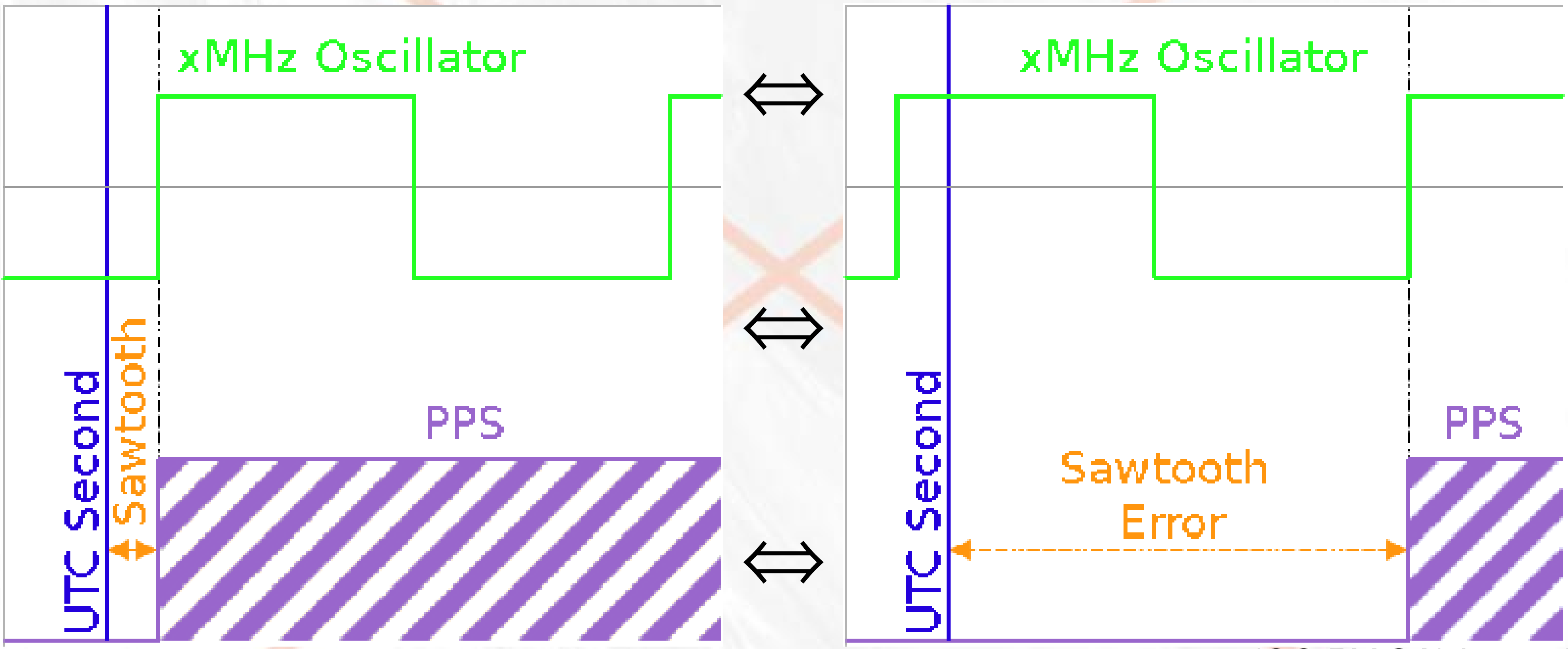
- The PPS on most modern **GPS** receivers are accurate to **10-100 ns**.
- General purpose **Computers** using a PPS can at best achieve **0.1 - 5 μs**.
- Some network capture devices can give higher precision.
- Higher precision can be useful for GPSDO OCXO characterisation.

[skip] **<u>Sawtooth is not "real" noise.</u>**

- Most receivers use the closest zero crossing of an internal free running oscillator to produce their PPS.
- As the **phase** of the oscillator moves over time then the distance to the **UTC second varies**.
- Timing receivers include this difference in their serial output.

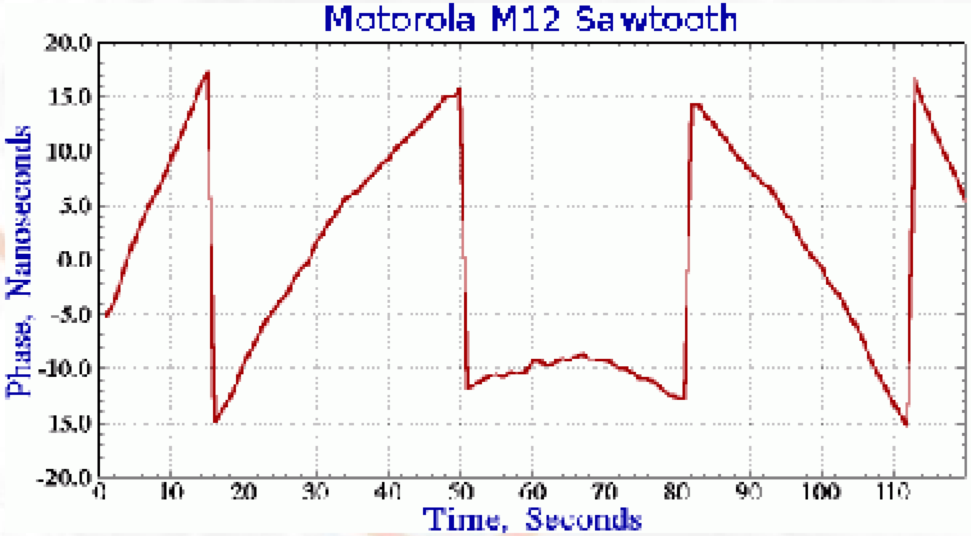
[skip] **<u>Sawtooth is not “real” noise.</u>**

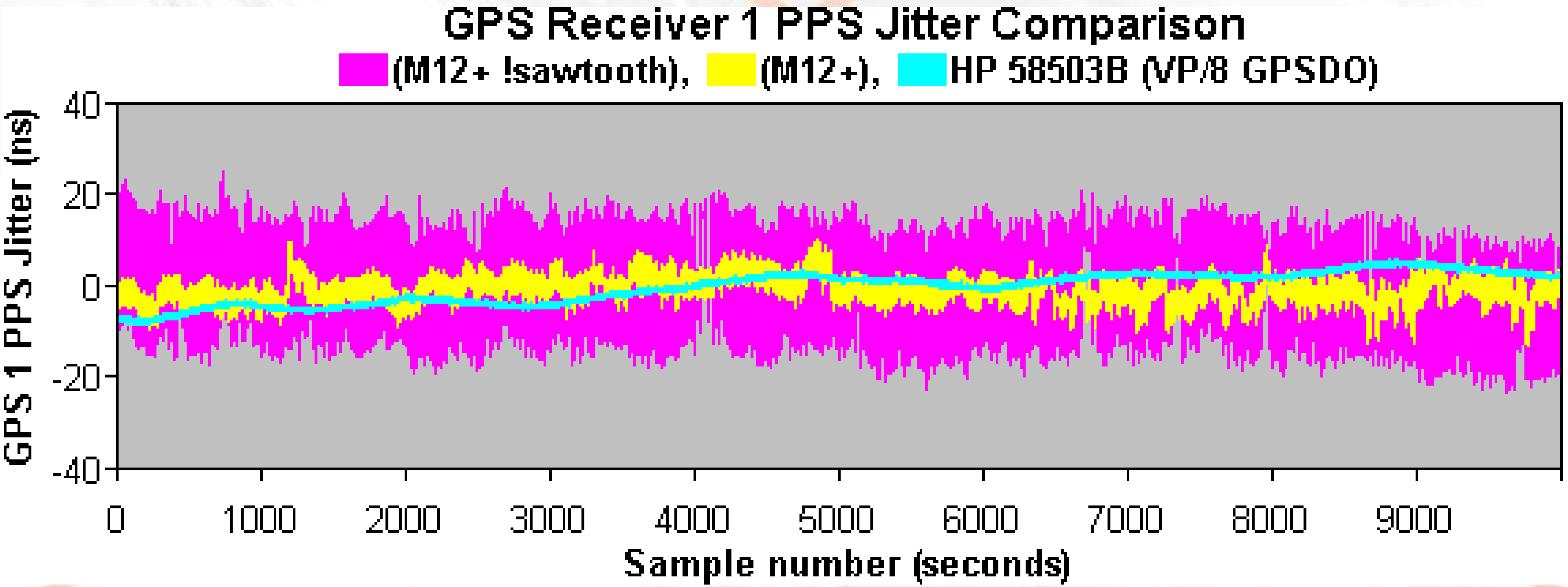
Free running oscillator vs UTC PPS:



The phase/error changes over time.

[skip] **Sawtooth is not "real" noise.**





FROM: http://leapsecond.com/pages/m12/ (with permission)

GPS Noise Summary:

2-20 ns	Short term GPS noise: can NOT be corrected, only averaged.
10-200 ns	Sawtooth errors: CAN be corrected or offsets used in calculations.
10-100 ns	Environmental wander. DGPS may correct common mode errors.
1-5 μs	Computer PPS timestamp jitter.
0.1-5 ms	Network & USB timestamp jitter.
1-10 ms	Computer temperature effects.
>100 ms	Computer power saving.

Timing Limits cheat sheet:

2-20 ns Short term GPS noise: can NOT be corrected, only averaged.

10-200 ns Sawtooth errors: CAN be corrected or offsets used in calculations.

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>100 ms Computer power saving.

Traceability to UTC.

- **UTC** is the agreed international **legal time scale** (love it or hate it).
- UTC is derived from EAL/TAI – a collaboration of national timing labs and is calculated retrospectively.
- UTC differs from TAI by an integer number of **leap seconds**.
- Local time is an offset from UTC.

Leap seconds and GPS.

- GPS has **no leap seconds** so differs from UTC by an integer number.
- This offset is given in the GPS almanac, even with good reception can take up to **12½ minutes** receive.
- Until the receiver has the almanac the wrong time maybe given.
- **IF** the offset is ever/correctly **applied**.

Going from GPS to UTC.

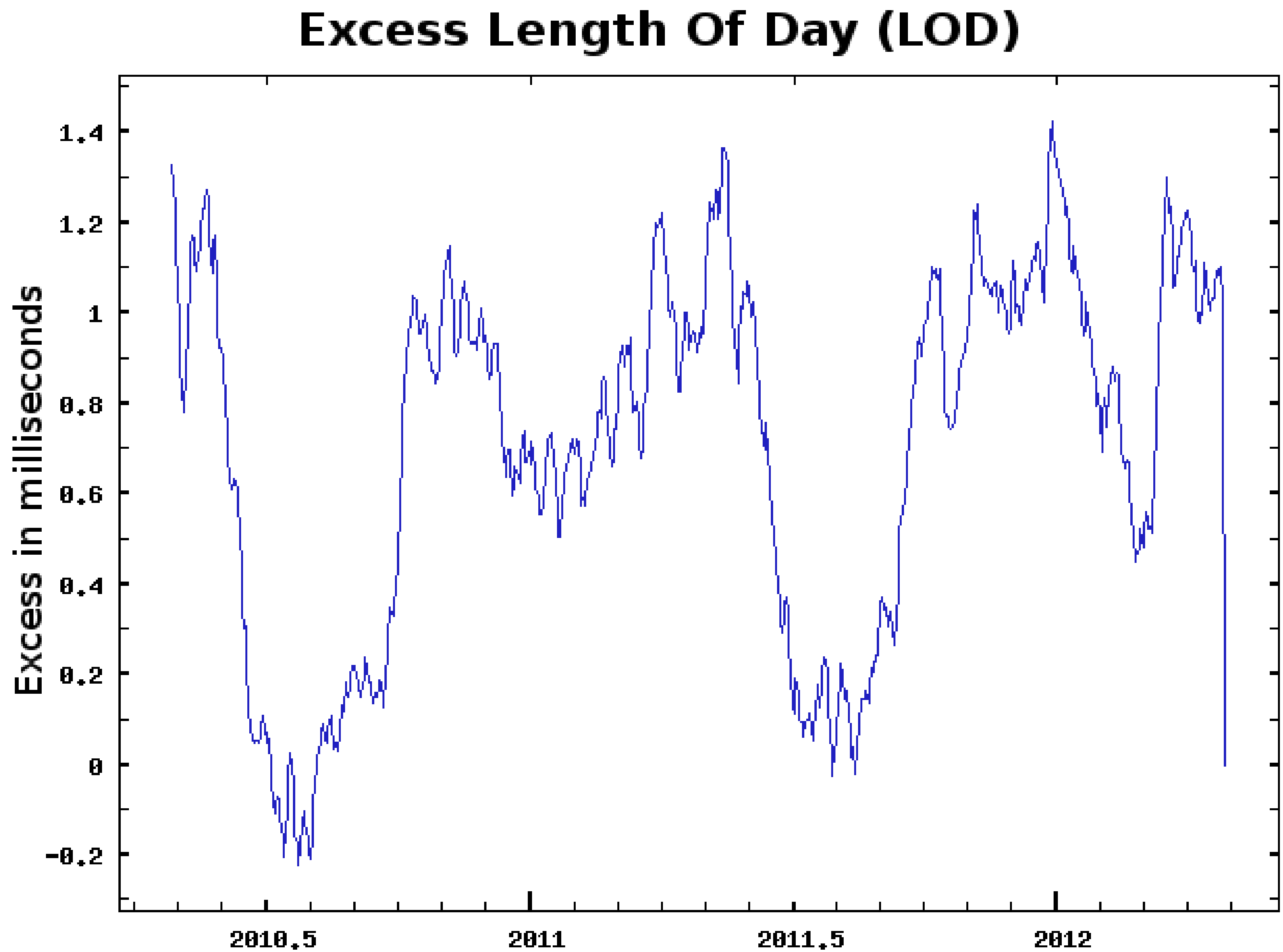
- Multiple levels of indirection,
  GPS+leap secs → UTC(USNO) → UTC
- Differences between UTC(UNSO) and UTC(BIPM) are typically only at the **nanoseconds level**.
- Other constellations are based on their own UTC standard.
  e.g. UTC(SU)(with **rubber seconds!**)

THE END..

All I want for Christmas are NO more leap seconds.

- Proposals to stop adding them have been around for over 15 years.
- UN standards vote is in Jan 2012.
- Astronomers are fighting strongly.
- Like other global **geopolitical issues** it will be agreed upon … eventually.

Leap seconds are unpredictable!



FROM: http://maia.usno.navy.mil/

“In what month was the Russian October Revolution”

Answer: November

It took 341 years for the Gregorian calendar to replace the Julian.

How long will it take before we get leap seconds fixed?

More Information.

- LinuxPPS

  http://wiki.enneenne.com/

- Time-Nuts mailing list:

  http://www.febo.com

  http://www.leapsecond.com/

  http://www.tapr.org/

- European Space Agency wiki:

  http://navipedia.net/